— HEAVY QUARK PHENOMENOLOGY —
$B \to \phi K^{(*)}$ CPV/POLARIZATION, AND COLLIDER IMPLICATIONS

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The hint for BSM CP violation in $B \to \phi K_S$ is now more confused, but the ϕK^* polarization anomaly seems real. We present a picture based on a flavor-mixed, right-handed "strange-beauty" squark $\widetilde{sb}_{1R}$, driven light by the large $\tilde{s}_R$-$\tilde{b}_R$ squark flavor mixing, which carries a unique new CP phase. The $\widetilde{sb}_{1R}$ could impact on $S_{\phi K_S}$ (or alternatively $S_{\eta' K_S}$), B_s mixing, $\sin 2\Phi_{B_s}$, $S_{K_S\pi^0\gamma}$ and other $b \to s$ transitions, and can be searched for directly at the Tevatron. Whether SM or BSM, a heuristic model is given where transverse ϕK^* polarization descends from the gluon helicity of on-shell $b \to sg$.

1 Introduction

1.1 *Baryon # Violating $\tau/c/b$ Decays?*

Let me start by disclaiming a host of seemingly interesting baryon number violating τ, D and B decays.[1] After submission, we found that the stringent $p \to \pi\nu$ bound implies $\mathcal{B}(\tau \to \bar{p}\pi^0) < 10^{-38}$, and slightly weaker bounds apply to $\tau \to \bar{\Lambda}\pi^-$ by a weak insertion. This agrees with an argument put forward by Marciano in 1995. Interestingly, Marciano's remark did not stop CLEO, in 1999, from following the 1992 search by ARGUS for $\tau \to \bar{p}\pi^0$; this year Belle searched for $\tau \to \bar{\Lambda}\pi^-$. Similar arguments apply to D and B decays and Ref. 1 will be updated.

1.2 *Heavy Quarks and New Physics*

The $b \leftrightarrow s$ transitions are arguably *the* current frontier for New Physics (NP). There is no sign of deviation in $b \leftrightarrow d$ phenomena such as B_d mixing and $\sin 2\Phi_{B_d}$, but nagging "discrepancies" in comparing $B \to K\pi$ and $\pi\pi$ transitions have existed since 1999.

In 2003 Belle suggested $\sin 2\Phi_{B_d \to \phi K_S}$ could be of opposite sign to $\sin 2\Phi_{B_d} \cong +0.73$. By adding an equivalent amount of data, Belle[2] now finds $\sin 2\Phi_{B_d \to \phi K_S} \simeq 0$, while BaBar's result[3] is of the "right" sign and only 1σ below 0.73. However, BaBar now finds $\sin 2\Phi_{B_d \to \eta' K_S} \simeq 0.27$ which seems low, although Belle finds 0.65 and is consistent with 0.73. But Belle and BaBar agree on $\sin 2\Phi_{B_d \to K_S\pi^0,\, K^+K^-K_S} \sim 0.3$, 0.5, which offers some support for a lower $\sin 2\Phi_{B_d \to \eta' K_S}$. Confirmation of a low ϕK_S or $\eta' K_S$ value would indicate NP.

NP could also emerge in $b \to s\ell^+\ell^-$, a large Δm_{B_s}, or $\sin 2\Phi_{B_s} \neq 0$. Another possibility would be[4] finding $b \to s\gamma_R$ (vs. γ_L from SM). This can now be probed, thanks to "K_S-tagging" technique developed by BaBar, by searching for $\sin 2\Phi_{B_d \to K_S\pi^0\gamma} \neq 0$. Thus, the study of $b \leftrightarrow s$ transitions offers a probe of NP for decades to come.

2 Light $\widetilde{sb}_{1R}$ and ϕK_S ($\eta' K_S$) CPV

The gist of our model[4] is a two-particle system consisting of a right-handed, flavor-mixed $\widetilde{sb}_{1R}$ squark, of order 200 GeV hence rather light, and $\tilde{g}$ of order 500–800 GeV. All other SUSY particles (except the possibility of bino $\tilde{\chi}_1^0$) are at 1–2 TeV scale because of low energy FCNC constraints. The $\widetilde{sb}_{1R}$ squark brings in *a unique new CPV phase* σ from $\tilde{s}_R$ and $\tilde{b}_R$ squark mixing, as phase freedom has been used up in quark sector.

As right-handed flavor mixing is the least probed part of SM, a light $\widetilde{sb}_{1R}$ squark could be just the right particle to emerge from $b \leftrightarrow s$, *in our era of heavy flavor factories.*

A light 500 GeV gluino seemed[4] needed

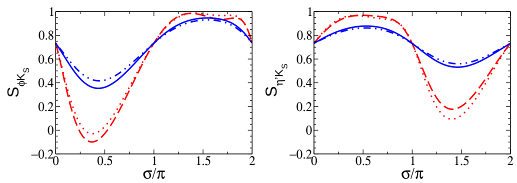

Figure 1. $S_{\phi K_S}$ and $S_{\eta' K_S}$ vs σ for $m_{\widetilde{sb}_1} = 200$ GeV. Solid, dotdash (dash, dots) lines are for common squark mass $\widetilde{m} = 2$, 1 TeV, $m_{\tilde{g}} = 0.8$ (0.5) TeV.

with the 2003 Belle result on ϕK_S. Indeed, one can see from Fig. 1 that $\sin 2\Phi_{B_d\to\phi K_S} < 0$ is rather drastic. We stopped at 500 GeV only for fear of FCNC bounds, and would resort to large hadronic factors[4] had a negative result persisted.

The case for $\sin 2\Phi_{B_d\to\phi K_S} < 0$ has softened this year, but new CPV results of Belle and BaBar are not in good agreement in ϕK_S, $\eta' K_S$ and $f_0(980)K_S$. We ignore the latter since Belle and BaBar are of opposite sign and the production dynamics for $f_0(980)$ is not known. We now see too possibilities, due to the anticorrelation (in σ) between[4,5] $\sin 2\Phi_{B_d\to\phi K_S}$ and $\sin 2\Phi_{B_d\to\eta' K_S}$:

- *Scenario 1* — If we take the Belle/BaBar average value of $\sin 2\Phi_{B_d\to\phi K_S} \sim 0.3$ and the new Belle result of $\sin 2\Phi_{B_d\to\eta' K_S} \simeq 0.65$, then a more pleasant (in regards FCNC) $m_{\tilde{g}} \sim 700$ GeV with $\sigma \sim \pi/2$ would suffice.
- *Scenario 2* — If the new BaBar result of $\sin 2\Phi_{\eta' K_S} \sim 0.27$ reflects some truth, let us combine with Belle and use ~ 0.45, but now take $\sin 2\Phi_{B_d\to\phi K_S} \sim \sin 2\Phi_{B_d}$, then one could have a different solution of $\sigma \sim 3\pi/2$, again with $m_{\tilde{g}} \sim 700$ GeV.

We emphasize these two new scenarios beyond published[4] results in this proceedings. Whether *Scenarios 1* or *2*, the NP effect is still large, hence the light $\widetilde{sb}_{1R}$ with its

1) large effective s-b mixing,
2) a unique new CPV phase, and
3) right-handed *strong* dynamics

involving the gluino, provides a natural setting. We stress that the model is well motivated in its own right:[6] any underlying *approximate* Abelian flavor symmetry would imply[7] large right-handed down flavor mixings, *with* s_R-b_R *mixing* $\sim$ *1.* Invoking SUSY, large flavor mixing repeats with squarks, and the strong dynamics in face of FCNC constraints demand the need for 4 texture zeros in the down-type quark mass matrix.[6]

When no evidence emerged for NP effects involving $b \leftrightarrow d$, we turned to decoupling d flavor, which decouples one from many L.E. constraints. We then found[8] the interesting result that, not only near maximal $\tilde{s}_R$-$\tilde{b}_R$ mixing could possibly drive $\widetilde{sb}_{1R}$ light (with some tuning), the RR mixing effects are well hidden in $b \to s\gamma$: it is the induced LR mixing effects that drive sensitivity near $\sigma \sim \pi$.

$B \to K^*\gamma$ and $b \to s\gamma$ illustrates FCNC constraints and computational techniques. The effective $b \to s\gamma$ transition is induced by the r.h. (l.h.) $O_{11}^{(\prime)}$ operator with coefficient $c_{11}^{(\prime)}$, arising from t-W loop in SM ($\widetilde{sb}_{1R}$-$\tilde{g}$ loop). To get $B \to K^*\gamma$ rate, one introduces the $B \to K^*$ form factor. For 200 GeV $\widetilde{sb}_{1R}$ and $m_{\tilde{g}} = 500$ GeV, $\pi/2 < \sigma < 3\pi/2$ is[8] ruled out by $b \to s\gamma$ data due to LR mixing effects, but the whole range is allowed for $m_{\tilde{g}} = 800$ GeV. For hadronic modes such as $B \to \phi K_S$, the $\widetilde{sb}_{1R}$ mainly[6] feeds the color-dipole O'_{12} operator (analogous to O'_{11}), but now one has large hadronic uncertainties.

So what are the implications for *Scenarios 1* or *2* for the near future? The situation is more relaxed with $m_{\tilde{g}} \sim 700$ GeV now allowed. Δm_{B_s} would still be larger than SM value, but would lie in the measurable 40–80 ps^{-1} range. However, finding a large Δm_{B_s}, though confirming NP, cannot tell apart the two scenarios; CPV measurements are needed. Besides confirmation of either $\sin 2\Phi_{B_d\to\phi K_S}$ or $\sin 2\Phi_{B_d\to\eta' K_S}$ being low, with $K_S\pi^0$ (model dependence very similar to $\eta' K_S$) modes as crosscheck but providing no further insight (due to hadronic uncertainties[4]), one needs some additional CPV measurement to resolve σ.

We plot $\sin 2\Phi_{B_s}$ and $\sin 2\Phi_{B_d\to K_S\pi^0\gamma}$

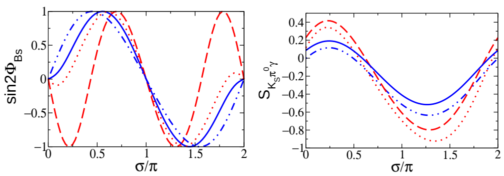

Figure 2. $\sin 2\Phi_{B_s}$ and $S_{K_S\pi^0\gamma}$ vs σ, with parameters and notation as in Fig. 1.

(where $K_S\pi^0$ forms a K^{*0}) in Fig. 2. The clean measurables Δm_{B_s} and $\sin 2\Phi_{B_s}$ have little hadronic uncertainties. They probe the $\widetilde{sb}_{1R}$-$\tilde{g}$ box hence are very sensitive to the masses involved, so provide information on these parameters. Furthermore, finding $\sin 2\Phi_{B_s} \sim +1$ or -1 would provide striking confirmation of *Scenarios 1* or *2*, i.e. either a low $\sin 2\Phi_{B_d\to\phi K_S}$ or $\sin 2\Phi_{B_d\to\eta' K_S}$, which should become clear by 2007.

Our two-particle NP model has 3 parameters, $m_{\widetilde{sb}_{1R}}$, $m_{\tilde{g}}$ and σ (one is less sensitive to a 4th, $m_{\widetilde{sb}_{2R}} \cong \sqrt{2}\,\widetilde{m}$), so a third clean measurable is needed. Parameters such as $\sin 2\Phi_{B_d\to\phi K_S}$ or $\sin 2\Phi_{B_d\to\eta' K_S}$ have murky hadronic uncertainties. Of course, a 200 GeV $\widetilde{sb}_{1R}$ squark can be searched for directly at the Tevatron, which we turn to later. Surprisingly, an additional clean CPV measurable exists: $B_d \to K^{*0}\gamma \to K_s\pi^0\gamma$.

The photon in $B \to K^*\gamma$ would be dominantly r.h. within SM. The strong r.h. $\widetilde{sb}_{1R}$-$\tilde{g}$ dynamics would produce a l.h. photon, $\propto c'_{11}$ at amplitude level. This allows for t-dep. CPV interference[9] between B^0 and $\bar{B}^0$ decays, suppressed by m_s^2/m_b^2 in SM. The formula for $\sin 2\Phi_{B_d\to K_S\pi^0\gamma}$ is simply

$$\frac{2|c_{11}c'_{11}|}{|c_{11}|^2+|c'_{11}|^2}\,\sin\left(2\Phi_{B_d}-\varphi_{11}-\varphi'_{11}\right), \quad (1)$$

where one sees that there are no hadronic uncertainties, with $|c'_{11}|$ and $\phi' \equiv \arg c'_{11}$ all computable in our model ($c_{11} \cong c_{11}^{\rm SM}$).

We see from Fig. 2 that $\sin 2\Phi_{B_d\to K_S\pi^0\gamma}$ can not only crosscheck the sign of $\sin 2\Phi_{B_s}$, the strength also offers very valuable information. In *Scenario 1*, $\sin 2\Phi_{B_d\to K_S\pi^0\gamma} \sim +0.1$ would be much harder to measure than $\sin 2\Phi_{B_d\to K_S\pi^0\gamma} \sim -0.6$ in *Scenario 2*. In this sense, we hope BaBar is right, that it is $\sin 2\Phi_{B_d\to\eta' K_S}$ (together with a few other PP modes) that is lower than $\sin 2\Phi_{B_d}$. After all, Belle's measurement of $\sin 2\Phi_{B_d\to\phi K_S}$ utilizing their upgraded SVD2 silicon detector (2004 data) is consistent with $\sin 2\Phi_{B_d}$. In any case, $\sin 2\Phi_{B_d\to K_S\pi^0\gamma}$ offers a third clean measurement to determine our model parameters from $b \leftrightarrow s$ studies.

3 ϕK^* Polarization Puzzle

Belle and BaBar now agree[2] on the longitudinal fraction $f_0 \cong 0.5$ in $B \to \phi K^*$, and transverse $f_\perp \simeq f_\parallel \cong 0.25$. This confirms the ϕK^* polarization puzzle since last year, against the factorization expectation of $f_0 = 1-\mathcal{O}(1/m_b^2)$; $f_\perp/f_\parallel = 1+\mathcal{O}(1/m_b)$ now seems respected. Since $f_0 = 1$ holds in tree dominant $\rho^+\rho^-$ and $\rho^+\rho^0$ modes, and seemingly for $\rho^0 K^{*+}$, the quest this year has been whether the naively pure $b \to s\bar{d}d$ penguin $\rho^+ K^{*0}$ mode emulates ϕK^* ($b \to s\bar{s}s$).

Indeed, Belle finds $f_0 \simeq 0.50$ for $\rho^+ K^{*0}$, while BaBar finds 0.79. But they disagree on rate ($\simeq 6.6\times10^{-6}$ vs 17.0×10^{-6}), so we can only conclude $f_0(\rho^+ K^{*0}) < 1$.

We proposed[10] a heuristic but *ad hoc* picture (Fig. 3) to account for the ϕK^* polarization anomaly. Our observation starts with $B \to K^*\gamma$. The K^* is purely transverse here because the photon is transverse. Inclusive $b \to s\gamma$ has rate $\sim 3\times10^{-4}$, and has a gluonic cousin of $b \to sg$, which has rate $\sim$ few $\times\,10^{-3}$ (0.1% in[11] SM). Clearly *this on-shell gluon is transverse*, but unlike the photon which immediately escapes, the gluon "fragments" into a "jet". $f_0 \cong 0.5$ means

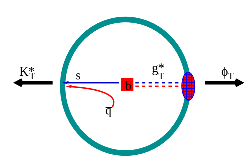

Figure 3. Heuristic picture for ϕ_T emission.

transverse $B \to K_T^* \phi_T \sim 5 \times 10^{-6}$. While $B \to K^* \gamma$ is about 10% of $b \to s\gamma$, if only one per mille of $b \to sg$ gives $B \to K_T^* \phi_T$, the ϕK^* anomaly is accounted for. The "gluon remnant" (left at hadron surface) and the recoil s and spectator $\bar{q}$ quark form a color singlet. We introduced a new hadronic parameter for $B \to \phi_T K_T^*$, and as corollary, ωK^*.

Our gluon fragmentation picture applies to both SM and our $\widetilde{sb}_{1R}$ model. For the latter, with softening of the ϕK_S anomaly (alternatively $\eta' K_S$), we expect T violating triple products to be consistent with present data, while CPV results are not yet reported.

We note that the singlet nature of the gluon implies that this process does not affect charged vector meson or ρ^0. If $f_0(\rho^+ K^{*0}) = 0.5$ as suggested by Belle, we'll probably accept defeat. However, if the value is 0.8, we suggest disentangling isospin components, since transverse $B \to \phi_T K_T^*$ and $\omega_T K_T^*$ can rescatter into $I = 1/2$ part of ρK^*.

4 Collider Search for Light $\widetilde{sb}_{1R}$

Even though B studies can fully determine $m_{\widetilde{sb}_{1R}}$, $m_{\tilde{g}}$ and the new CP phase σ, nothing beats direct observation of a new particle. In our TeV scale SUSY model, the $\widetilde{sb}_{1R}$ is *driven light by large flavor mixing*, which is unusual. We have shown[8] that a bino $\widetilde{\chi}_1^0$ lighter than even 100 GeV is allowed by $b \to s\gamma$. But unlike the $\widetilde{sb}_{1R}$, we have no argument for why $\widetilde{\chi}_1^0$ (nor the gluino itself) is light.

We stress that standard $\tilde{b}$ squark limit is diluted by dual s-b flavor of the $\widetilde{sb}_{1R}$, since $\widetilde{sb}_{1R} \to b\widetilde{\chi}_1^0$, $s\widetilde{\chi}_1^0$ (or gravitino $\widetilde{G}^0$). This should be kept in mind for direct search. A 200 GeV squark certainly can be uncovered by the Tevatron, and a few hundred raw events per few fb^{-1} luminosity is expected, with $q\bar{q}$ process for standard $\tilde{b}$ squark production dominating over gg. Discovery is not a problem, but the flavor mixing angle $\sin^2\theta_m$ controls the b fraction, hence double b-tagged events are diminished. Nevertheless good b-tagging is crucial, and the single vs. double tag ratio contain information on $\sin^2\theta_m$.

Table 1. Tevatron cross sections (fb) for $\widetilde{sb}_{1R}$.

Mass	0 b-tag	1 b-tag	2 b-tag
150	283	243	51
200	68	61	14
250	16	15	3.3
300	4.0	3.7	0.83
350	1.0	0.93	0.21

Let us take maximal mixing, i.e. $\sin^2\theta_m = 0.5$ as reference. Table 1 gives cross sections at the Tevatron, where we see the $\widetilde{sb}_{1R}$ can be discovered (> 10 events with low background) up to 300 GeV.

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